QCD Rencontres de Moriond
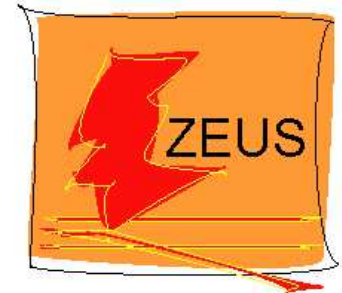
March 13-20, 2010   La Thuile, Valle d'Aosta,Italy

Search for new physics at HERA using combined H1 and ZEUS data

S. Levonian (DESY)

- HERA Collider and Experiments
- Model Independent Search
- Multi-Lepton Topologies
- Events with Isolated Leptons and Missing Transverse Momentum
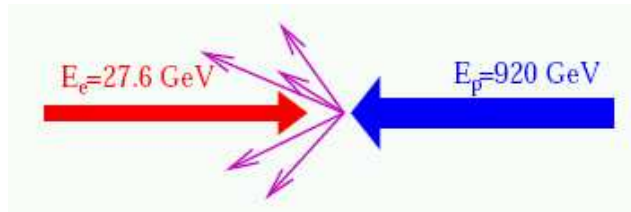- Summary

The HERA Collider

HERA-1 (1993-2000) $\simeq$ **120 pb**$^{-1}$
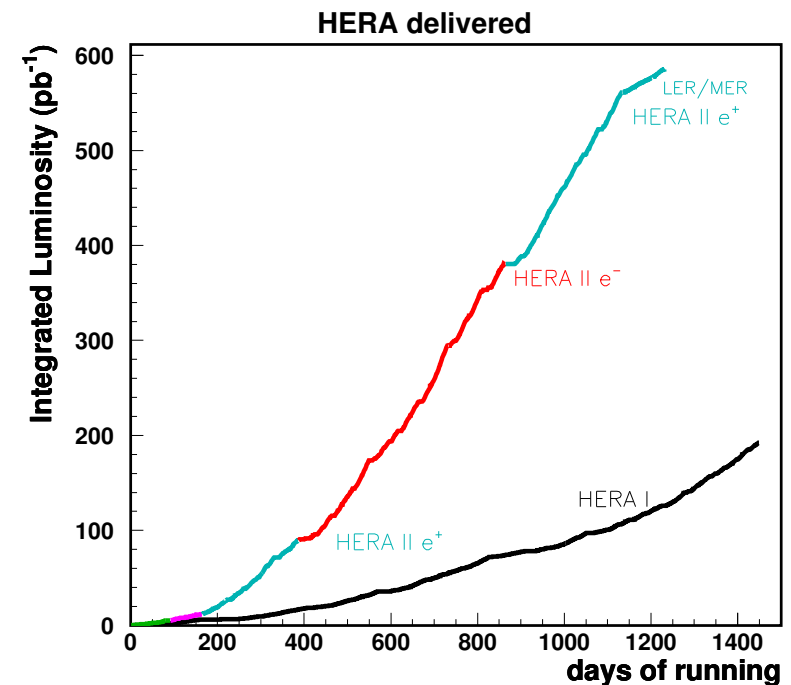
HERA-2 (2003-2007) $\simeq$ **380 pb**$^{-1}$

Final Data samples

H1+ZEUS: 2×0.5 fb^{-1}

$E_e = 27.6$ GeV $E_p = 920$ GeV

- 1998 E_p upgrade: $820 \Rightarrow 920$ GeV
  ($\sqrt{s}$: $301 \Rightarrow 319$ GeV)

- 2001 HERA-2 upgrade: $\mathcal{L} \times 3$, Polarised e^+/e^-

HERA delivered

Integrated Luminosity (pb^{-1})

LER/MER
HERA II e$^+$

HERA II e$^-$

HERA II e$^+$

HERA I

days of running

H1 + ZEUS Combination

- **Motivation**

  ▷ HERA data will remain unique for a long time $\Rightarrow$ Fully exploit their potential
  ($1\text{fb}^{-1} \Rightarrow$ sensitivity to rare processes, $\sigma \leq 0.1$ pb)

- **Benefits**

  ▷ statistically limited samples: gain in statistical significance (e.g. searches)

  ▷ large statistics samples: also further improve systematics
  by cross calibration of the experiments (e.g. F_2 measurement)

- **Strategy** (for this combination)

  ▷ perform individual analyses optimally using detector capabilities

  ▷ determine common phase space, unify cuts against bgr, binning

  ▷ combine data (and SM predictions) bin by bin $\Rightarrow$ look for possible deviations

  ▷ measured cross sections are determined as weighted average

The Concept of Model Independent Search

- Perform model independent generic search (data vs SM)

- Identify promising topologies

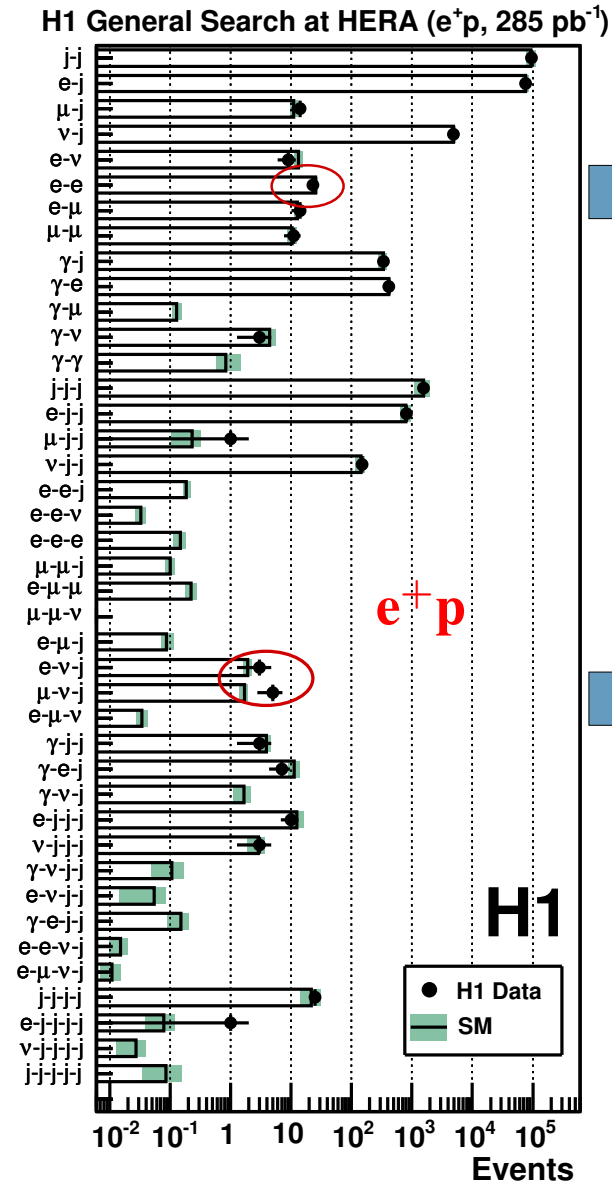- Make dedicated detailed analysis on those topologies

General search for New Phenomena

- Identify isolated ($D(\eta\phi) > 1$) particles (objects): e, μ, γ, j, ν

- Select events, having at least two objects with high $P_T > 20\,\text{GeV}$ in the detector acceptance ($10^o < \theta < 140^o$)

- Classify into exclusive channels containing from 2 to 5 objects

- Compare with SM predictions
  ⇒ **good overall agreement**
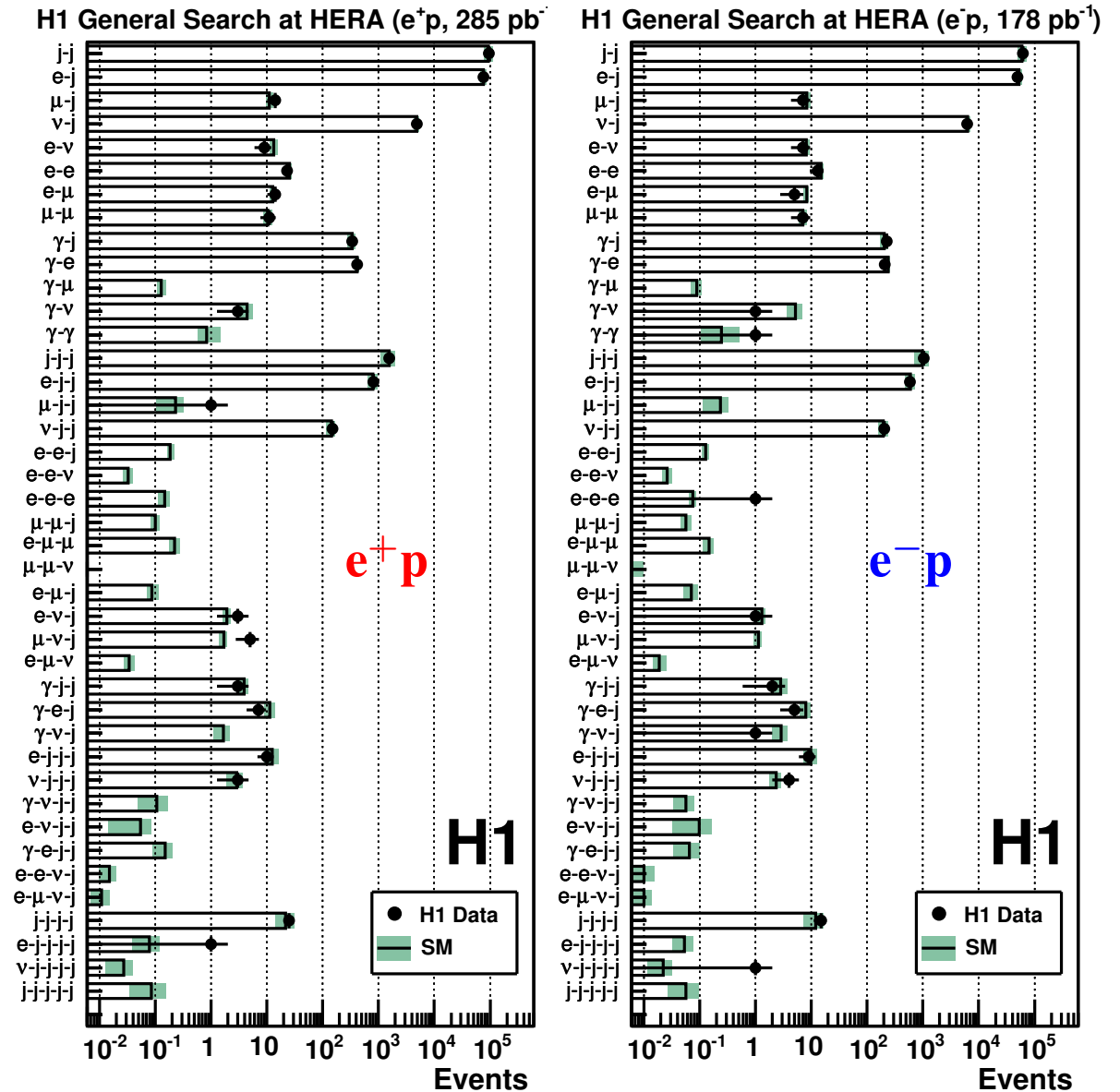
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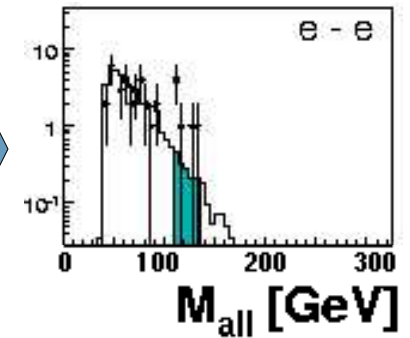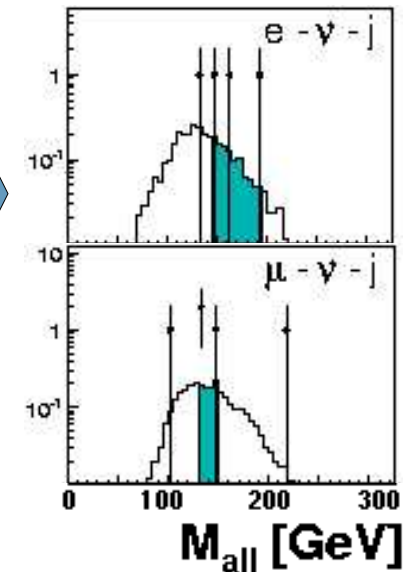- Find interesting regions with greatest deviations from SM in kin. distributions ($M_{\mathrm{all}}, \Sigma P_T$)

H1 Coll. PL B674 (2009) 257-268

H1 General Search at HERA (e⁺p, 285 pb⁻¹)

e^+p

H1

- H1 Data
- SM

Events

$e^\pm p$, 463 pb⁻¹

M_{all} [GeV]

biggest deviation in H1

M_{all} [GeV]
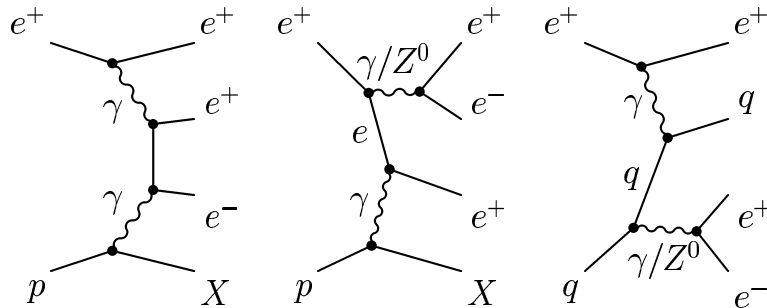
most interesting channels in HERA-1

Multi-lepton Events in H1 and ZEUS

- Clean signature, precise SM prediction (mainly via $\gamma\gamma$ process) - modelled using GRAPE

$\Rightarrow$ High sensitivity to new physics

- SM backgrounds: NC-DIS, QED Compton due to misidentification of h, γ as electrons
  (also small non-ep bgr from cosmics in multi-muon events)
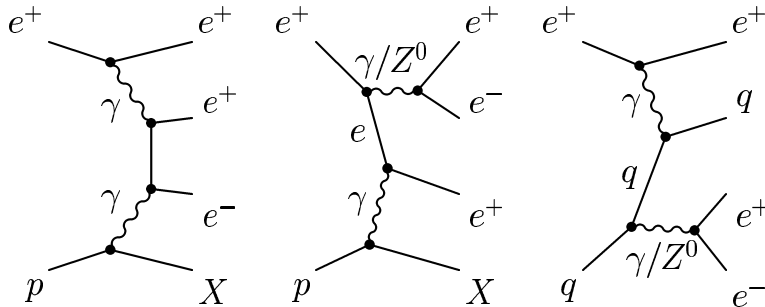
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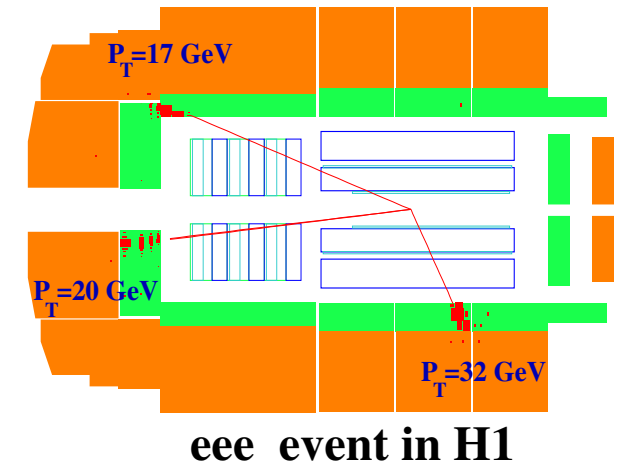
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eee event in H1

- Lepton selection
  e : $E > 10$ GeV (in $5^o < \theta < 175^o$), $E > 5$ GeV (in $\theta > 150^o$)
  μ : $P_T > 2$ GeV in the region $20^o < \theta < 160^o$

- Event selection
  At least two leptons must be found in the region
  $20^o < \theta < 150^o$ and have $P_T > 10,\ 5$ GeV

- Events are classified into mutually exclusive samples:
  $ee,\ eee,\ \mu\mu,\ e\mu,\ e\mu\mu,\ ...$

ZEUS

$e\mu\mu$

Multi-lepton Topologies and Measurement of $\sigma(\gamma\gamma \to l^+l^-)$

Multi-Leptons at HERA (0.94 fb^{-1})

Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
ee	873	895 ± 57	724 ± 41	171 ± 28
$\mu\mu$	298	320 ± 36	320 ± 36	< 0.5
$e\mu$	173	167 ± 10	152 ± 9	15 ± 3
eee	116	119 ± 7	117 ± 6	< 4
$e\mu\mu$	140	147 ± 15	147 ± 15	< 0.5
$(\gamma\gamma)_e$	284	293 ± 18	289 ± 18	4 ± 1
$(\gamma\gamma)_\mu$	235	247 ± 26	247 ± 26	< 0.5

Overall good agreement observed with the SM prediction

use $\gamma\gamma$ selections to measure the cross sections in photoproduction regime

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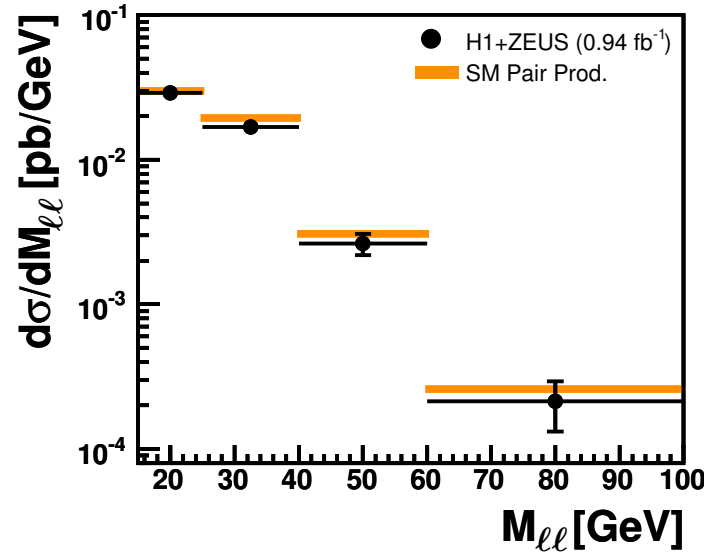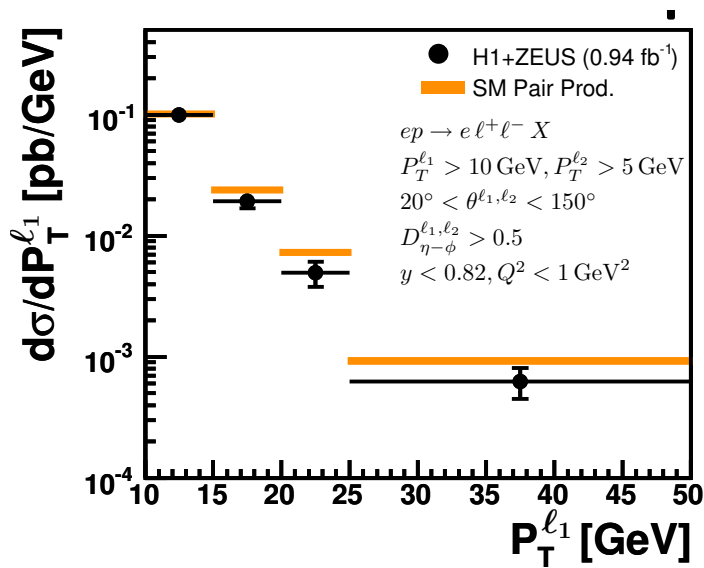use $\gamma\gamma$ selections to measure the cross sections in photoproduction regime

$Q^2 < 1$ GeV^2

Total visible cross section measured $0.66 \pm 0.03(\text{stat.}) \pm 0.03(\text{sys.})$ pb in good agreement with SM prediction 0.69 ± 0.02 pb (from GRAPE MC)
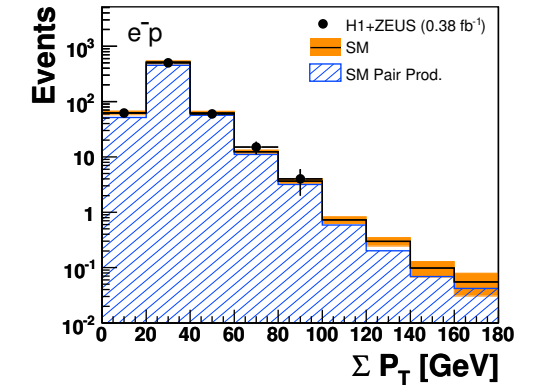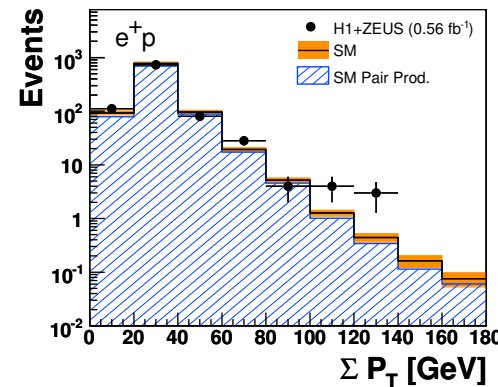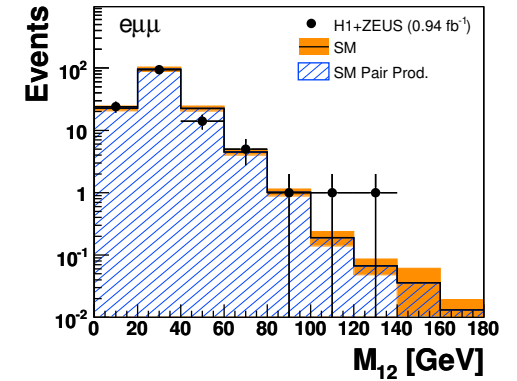
Multi-lepton Events at High Mass and High ΣP_T

Multi-Leptons at HERA (0.94 fb^{-1})				
$M_{12} > 100$ GeV				
Sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p collisions (0.56 fb^{-1})				
ee	4	1.68 ± 0.18	0.94 ± 0.11	0.74 ± 0.12
$\mu\mu$	1	0.32 ± 0.08	0.32 ± 0.08	< 0.01
$e\mu$	1	0.40 ± 0.05	0.39 ± 0.05	< 0.02
eee	4	0.79 ± 0.09	0.79 ± 0.09	< 0.03
$e\mu\mu$	2	0.16 ± 0.04	0.16 ± 0.04	< 0.01
e^-p collisions (0.38 fb^{-1})				
ee	0	1.25 ± 0.13	0.71 ± 0.11	0.54 ± 0.08
$\mu\mu$	0	0.23 ± 0.10	0.23 ± 0.10	< 0.01
$e\mu$	0	0.26 ± 0.03	0.25 ± 0.03	< 0.02
eee	0	0.49 ± 0.07	0.49 ± 0.07	< 0.03
$e\mu\mu$	0	0.14 ± 0.05	0.14 ± 0.05	< 0.01
All data (0.94 fb^{-1})				
ee	4	2.93 ± 0.28	1.65 ± 0.16	1.28 ± 0.18
$\mu\mu$	1	0.55 ± 0.12	0.55 ± 0.12	< 0.01
$e\mu$	1	0.65 ± 0.07	0.64 ± 0.06	< 0.02
eee	4	1.27 ± 0.12	1.27 ± 0.12	< 0.03
$e\mu\mu$	2	0.31 ± 0.06	0.31 ± 0.06	< 0.01

| Multi-Leptons at HERA (0.94 fb^{-1})				
$\sum P_T > 100$ GeV				
Data sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p (0.56 fb^{-1})	7	1.94 ± 0.17	1.52 ± 0.14	0.42 ± 0.07
e^-p (0.38 fb^{-1})	0	1.19 ± 0.12	0.90 ± 0.10	0.29 ± 0.05
All (0.94 fb^{-1})	7	3.13 ± 0.26	2.42 ± 0.21	0.71 ± 0.10

12 events in high mass region found
9 from H1 and 3 from ZEUS
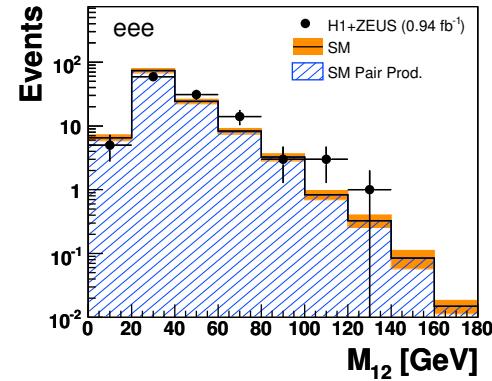
Events at high mass and high ΣP_T are observed by both H1 and ZEUS, but only in e^+p data. There the excess over SM has significance of 2.6σ

Events with Isolated Leptons and Missing P_T

- The main SM process in ep interactions leading to the event topology with high P_T isolated lepton in conjunction with large missing transverse momentum in the final state is single W production:
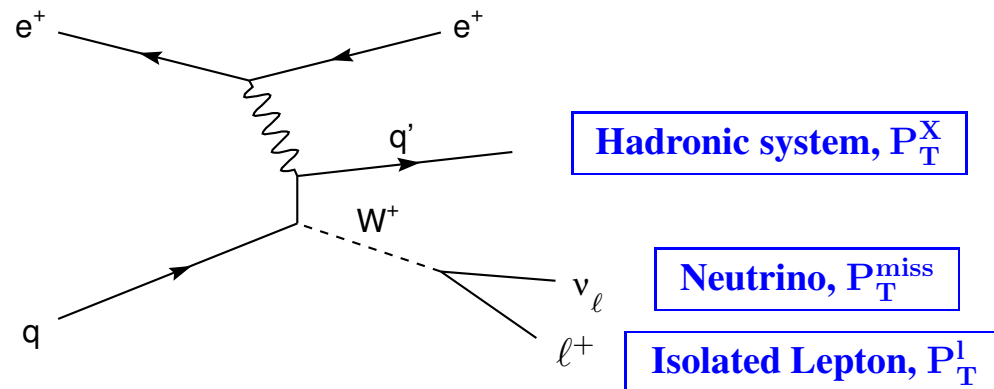
- W's are predominantly produced in NC reactions, but CC contributes as well at smaller level
  Even smaller ($\sim 3\%$) contribution to signal topology comes also from $Z^o \to \nu\bar{\nu}$ production

- Total W production cross section at HERA, as predicted by SM, is ~ 1.3 pb
  with $\sim 11\%$ of W decaying to each lepton flavour.
  It is modelled using EPVEC MC with NLO QCD corrections, leading to 15% uncertainty

- Main SM backgrounds are NC-DIS, CC-DIS and lepton pair production processes

Isolated Leptons and Missing P_T: Event Selection

- Common H1+ZEUS analysis phase space is defined as events with isolated e or μ satisfying $P_T > 10$ GeV, in the range $15^o < \theta < 120^o$ and $P_T^{\text{miss}} > 12$ GeV

- Electron and muon channels are exclusive, and are combined in the measurement and in the W production cross section determination

- Set of cuts applied to further reduce SM background, rejecting e.g. back-to-back topologies in NC and lepton pair production processes

- The overall H1(ZEUS) efficiency to select SM $W \rightarrow e\nu$ events is $30\%(31\%)$ and to select $W \rightarrow \mu\nu$ events is $11\%(9\%)$, as calculated using EPVEC
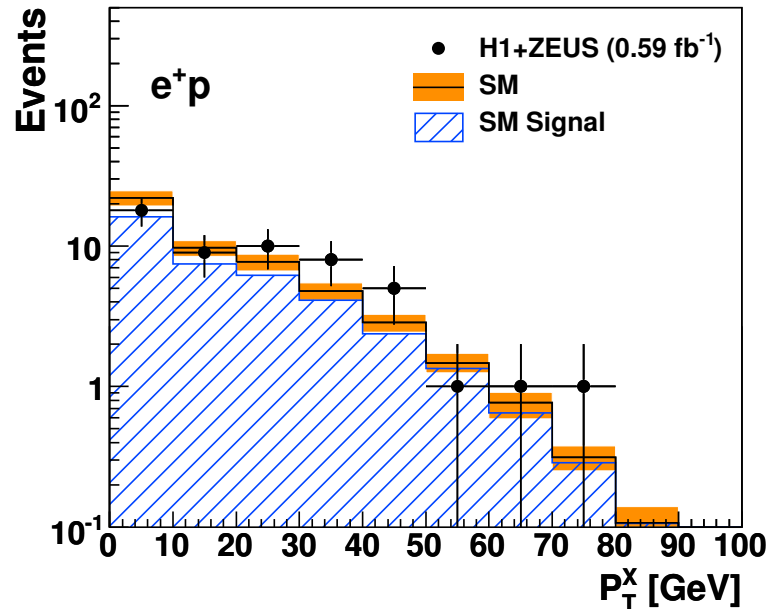

Isolated Electron

Neutrino ?

Hadronic Jet, X
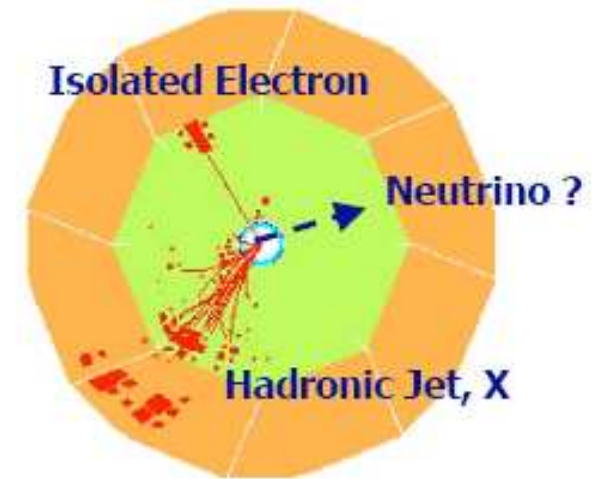
e + P_T^{Miss} event in H1

Isolated Muon

Hadronic Jet, X
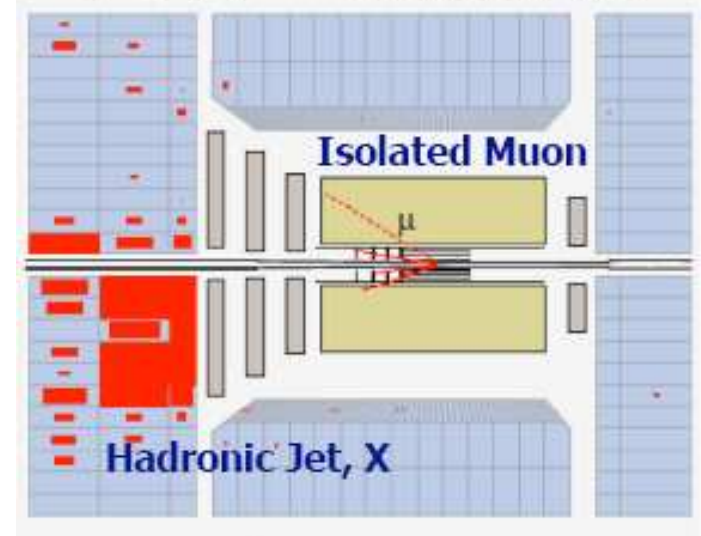
μ + P_T^{Miss} event in ZEUS

H1+ZEUS Isolated Leptons: e^+p Data

H1+ZEUS 1994–2007 e^+p 0.59 fb^{-1}		Data	SM Expectation			SM Signal			Other SM Processes		
Electron	Total	37	38.6	$\pm$	4.7	28.9	$\pm$	4.4	9.7	$\pm$	1.4
	$P_T^X > 25$ GeV	12	7.4	$\pm$	1.0	6.0	$\pm$	0.9	1.5	$\pm$	0.3
Muon	Total	16	11.2	$\pm$	1.6	9.9	$\pm$	1.6	1.3	$\pm$	0.3
	$P_T^X > 25$ GeV	11	6.6	$\pm$	1.0	5.9	$\pm$	0.9	0.8	$\pm$	0.2
Combined	Total	53	49.8	$\pm$	6.2	38.8	$\pm$	5.9	11.1	$\pm$	1.5
	$P_T^X > 25$ GeV	23	14.0	$\pm$	1.9	11.8	$\pm$	1.9	2.2	$\pm$	0.4

17 H1 + 6 ZEUS events at high P_T^X

- **2.4σ** excess in the data event yield at large P_T^X seen in H1 analysis is not confirmed in the ZEUS analysis

- Only about **1.9σ** excess remains in the common phase space of the combined H1+ZEUS analysis

H1+ZEUS Isolated Leptons: $e^{\pm}p$ Data

H1+ZEUS		Data	SM Expectation			SM Signal			Other SM Processes		
1994–2007 $e^{\pm}p$ 0.98 fb^{-1}											
Electron	Total	61	69.2	$\pm$	8.2	48.3	$\pm$	7.4	20.9	$\pm$	3.2
	$P_T^X > 25$ GeV	16	13.0	$\pm$	1.7	10.0	$\pm$	1.6	3.1	$\pm$	0.7
Muon	Total	20	18.6	$\pm$	2.7	16.4	$\pm$	2.6	2.2	$\pm$	0.5
	$P_T^X > 25$ GeV	13	11.0	$\pm$	1.6	9.8	$\pm$	1.6	1.2	$\pm$	0.3
Combined	Total	81	87.8	$\pm$	11.0	64.7	$\pm$	9.9	23.1	$\pm$	3.3
	$P_T^X > 25$ GeV	29	24.0	$\pm$	3.2	19.7	$\pm$	3.1	4.3	$\pm$	0.8

Overall good agreement is observed with the SM expectation

Extract σ_W

Single W Cross Section

- Determination of the Single W cross section is performed in the common analysis phase space, then extrapolated to the full phase space using EPVEC

- Branching ratio of W decays to leptons used to calculate the full W production cross section

- As there is no measurement in the $P_T^X < 12$ GeV bin in the muon channel, the electron channel is used under the assumtion of lepton universality:

$$\sigma_l^{allP_T^X} = \sigma_e^{P_T^X > 12} + \sigma_\mu^{P_T^X > 12} + 2\sigma_e^{P_T^X < 12}$$

Single W Production at HERA

- The total single W cross section (at $\sqrt{s} = 317$ GeV) $= 1.06 \pm 0.16(\text{stat.}) \pm 0.07(\text{sys.})$ pb in good agreement with SM prediction 1.26 ± 0.19 pb (from EPVEC at NLO)
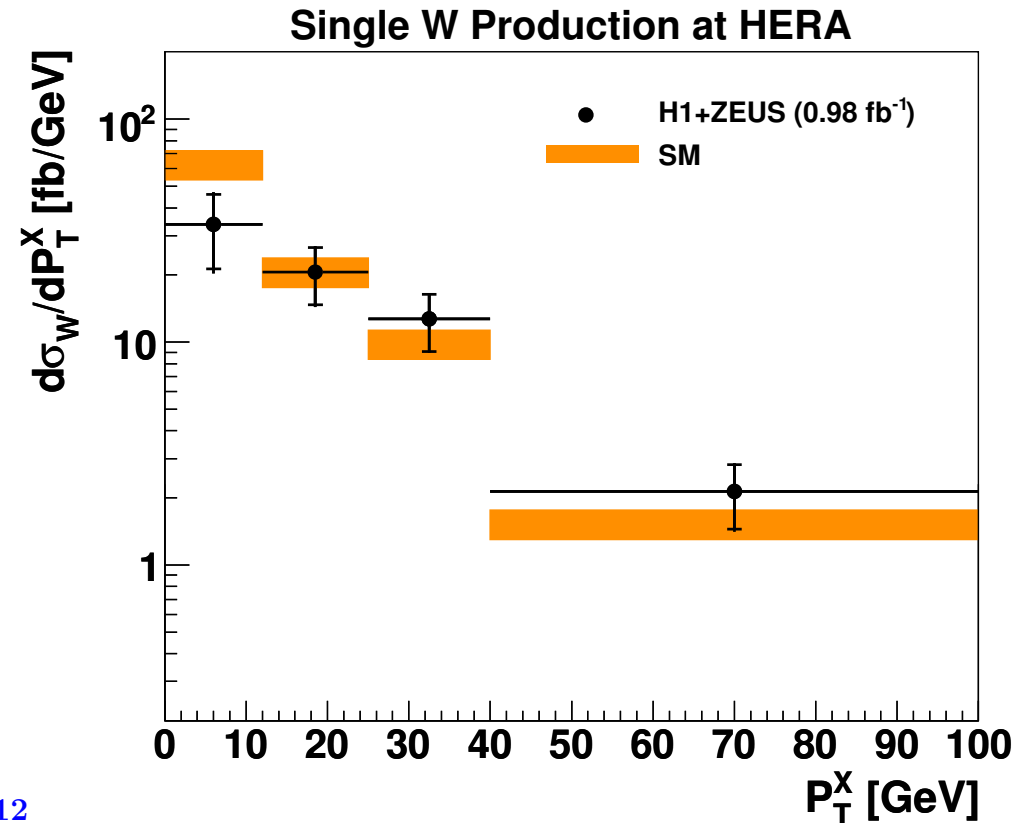
Summary

■ Combined H1 + ZEUS analyses have been performed to take advantage of full HERA statistics. 'The final word from HERA' is published on

- Multi-leptons: JHEP 0910:013 (2009)
- Isolated Leptons + P_T^{miss}: (JHEP 2/2010), arXiv:0911.0858 [hep-ex]

■ Cross sections of rare processes measured with greater precision as compared to individual publications.
A good agreement with the Standard Model is observed

■ Although interesting events are observed at high P_T and high mass in e$^+$p data, both in H1 and ZEUS, no evidence for new physics above 3σ is found

■ Standard Model survived full **HERA** dataset and is still in a good shape. Perhaps next challenge will come from the **LHC** ...